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# INTERCONNECTION OF BROADBAND ISLANDS VIA SATELLITE - EXPERIMENTS ON THE RACE II CATALYST PROJECT

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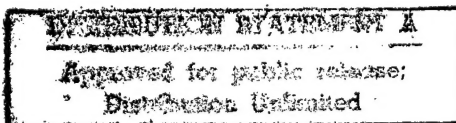
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## Abstract

This paper presents the performance studies of ATM via satellite based on experiments implemented by the RACE II CATALYST project R2074. The purpose of the project was to develop an ATM satellite link for the future B-ISDN services, particularly for the interconnections of the ATM testbeds which are in the form of broadband islands. Then initial ATM based B-ISDN can be introduced by interconnections of these broadband islands. The CATALYST project has developed the equipment to be able to interconnect newly developed ATM testbeds as well as the existing networks such as DQDB, FDDI and Ethernet. Experiments carried out, demonstrated the capability of the satellite ATM connections to support data, voice, video and multimedia applications. These experiments provided a real system demonstration of ATM via satellite. In the light of the experiment, this paper evaluates the performance model and the capacity of the ATM satellite equipment, and studies the relevant issues and the impact of ATM-via-satellite on the applications and the protocols.

## 1. Introduction

Since mid 1980s, research and development of the ATM based B-ISDN technology has made great progresses [CCIT91a-e] [ATMF94]. Now the technology has reached a mature stage and is introduced to the market for commercial development. A number of experimental ATM networks have been developed in Europe [SUN93], [LUCK94]. These experimental ATM networks are in the form of B-ISDN "islands". The CATALYST project (R2074) is a RACE II project to provide an ATM link via satellite for these broadband islands. In 1994, the project carried out experiments at the Laboratories of Alcatel Telespace in Nanteere near Paris. It has successfully demonstrated the capability of satellite ATM connections for interconnecting broadband networks and supporting various applications including data, voice, video and multimedia communications.



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The ATM based B-ISDN will not be a revolution but an evolution. Considering this the CATALYST satellite bridge has been designed to be able to interconnect the ATM networks as well as the existing networks such as the LANs and MANs. Figure 1 illustrates an example of configuration of the satellite demonstrator. A modular approach has been used in the design to interface different networks and the satellite, to convert network packets to and from ATM cells.

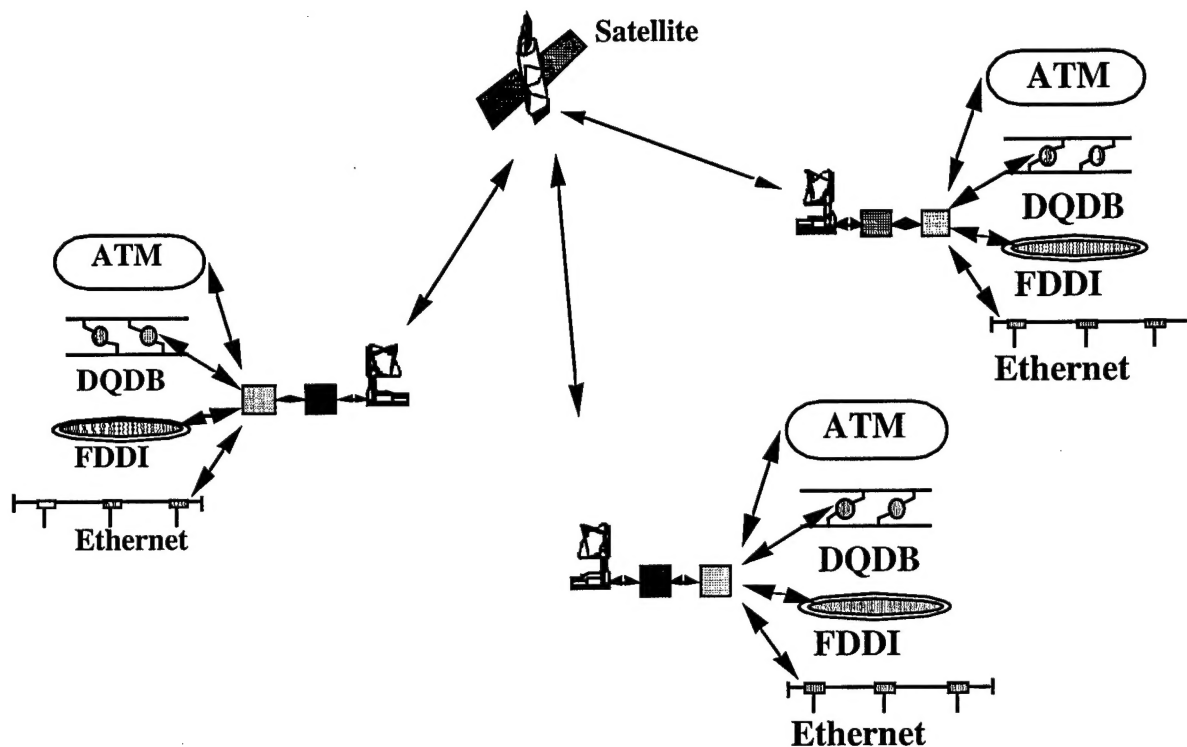


Figure 1. An example of the CATALYST demonstrator configuration

The satellite ATM equipment has to interface the networks with the capacities in the range of 10 to 150 Mbit/s (10 Mbit/s for Ethernet, 34 Mbit/s for DQDB, 100 Mbit/s for FDDI and 150 Mbit/s for ATM networks). The satellite link has a capacity of approximately 25 Mbit/s at present and will never be able to match the speed of optical fibre terrestrial networks. The satellite link capacity has to be shared by a number of earth stations when multiple broadband islands are interconnected. It is important to study the model of the satellite demonstrator to provide the required Quality of Service (QoS) with efficient utilisation of the satellite resource and effective traffic control mechanisms.

Due to the nature of satellite links, the effects caused by long propagation delay become a very important issue. For example, voice and video applications are more sensitive to the long delay than data applications. Delay variations can significantly degrade the QoS. The delay also affects throughput of the connections based on different protocols such as connection oriented and connectionless protocols. The connection oriented protocols requiring acknowledgements of packet arrival may need to increase the time-out parameter or window size to accommodate the long propagation delay (see [JACO92] for TCP extensions). Hence adjustment of existing protocols or development of new ones are required to support the B-ISDN applications efficiently.

This paper tries to study these issues including the effects on the applications and protocols. First, it describes the architecture and modelling of the ATM satellite equipment. Then it discusses the effect of long delay on the protocols and applications based on the model. It also discusses the resource management and traffic control mechanisms for the satellite system. Finally, the measured results are used as reference values to predict and evaluate the system performance. This study will be useful to design and selection of protocols for different applications to be supported by satellite ATM connections, and to the evaluation of the broadband islands which will evolve into the integrated broadband communications networks in the future.

## 2. ATM Satellite System Architecture and Model

In the current design, the satellite bridge is able to interface four types of networks: ATM, DQDB, FDDI and Ethernet. The interface to the satellite link is based on the time division multiple access (TDMA) techniques. The packets from the networks are converted into ATM cells and transmitted in the TDMA frame. Figure 2 compares the architecture of the ATM satellite network with the existing network architecture.

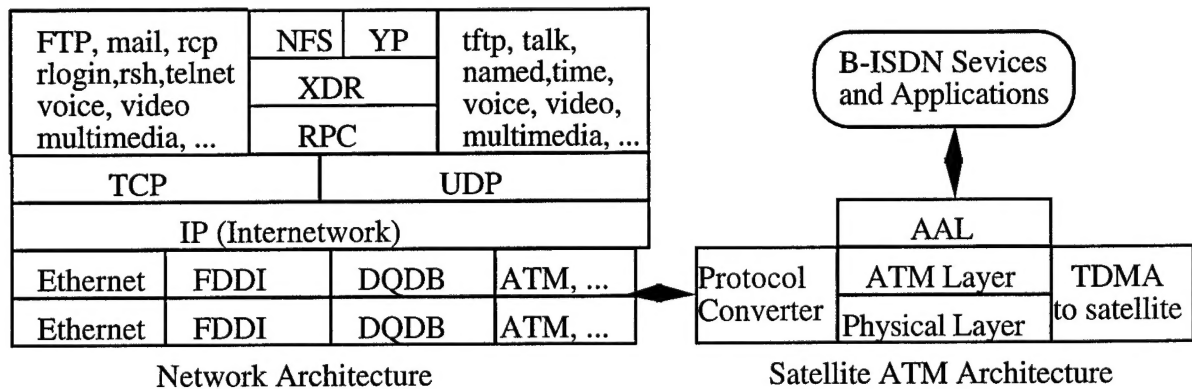


Figure 2. Architecture of existing networks and the satellite system.

The satellite ATM equipment consists of following modules: ATM line terminator (ATM-LT), Ethernet LAN Adaptation Module (E-LAM), FDDI LAN Adaptation Module (F-LAM), DQDB LAN Adaptation Module (DQDB-AM), Generic LAN ATM Converter (GLAC), ATM Adaptation Module (ATM-AM) and Terrestrial Interface Module for ATM (TIM-ATM). Figure 3 illustrates the model of the satellite equipment. The ATM-LT provides an interface with a speed of 155 Mbit/s between the ATM network and the satellite ATM equipment. It is also the termination point of the ATM network.

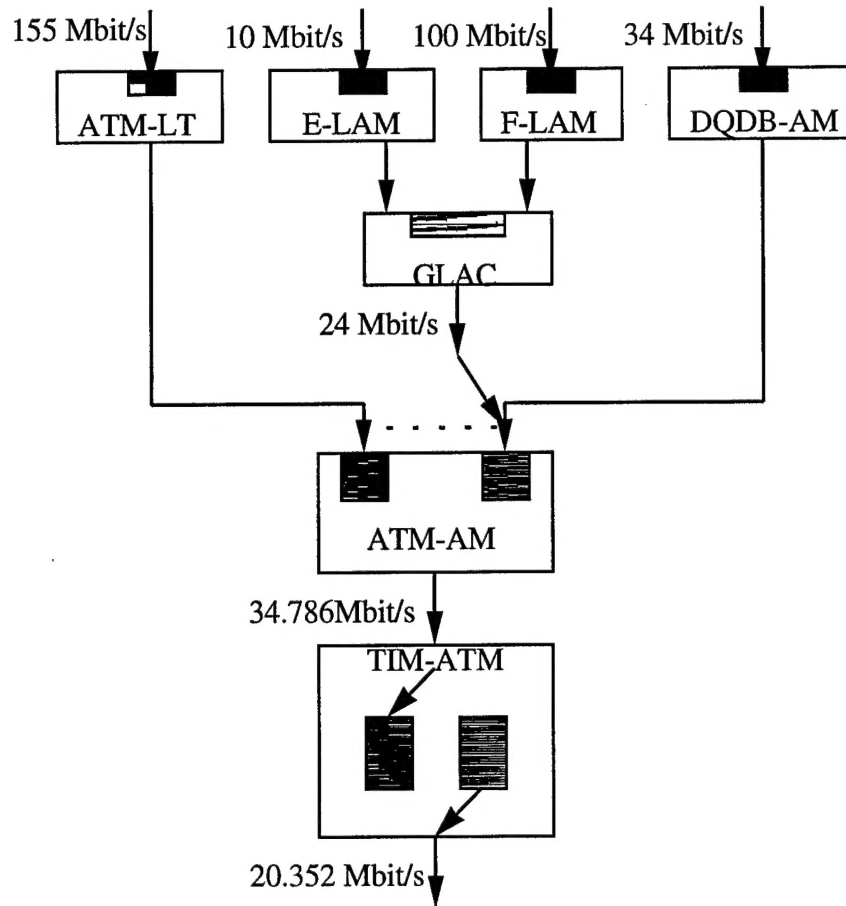


Figure 3. Model of the Satellite Bridge.

The E-LAM module provides an interface to the Ethernet local area network. It has a buffer of 64 Kbytes. The link speed at the interface is 10 Mbit/s. It passes the Ethernet packets to the GLAC module. The F-LAM module provides an interface to the FDDI network. It has a buffer of 8 Mbytes. The link speed at the interface is 100 Mbit/s. It passes the FDDI packets to the GLAC module. The DQDB-AM module provides an interface to the DQDB network with a small buffer. It converts DQDB packets into ATM cells and then passes to the ATM-AM. The link speed at the interface is 34 Mbit/s.

The GLAC module converts the FDDI and Ethernet packets into ATM cells, then passes the cells to the ATM-AM module. It has a buffer of 4 Mbytes. The ATM-AM module is an ATM Adapter. It multiplexes the ATM cell streams from the two ports into one ATM cell stream. It has buffers of 154 cells for port 0 and 77 cells for port 1. It passes the cells to the TIM-ATM module, limiting the maximum rate to 10 cells in 125 microseconds G.751 frame time.

The TIM-ATM module provides an interface between the satellite and terrestrial systems. The module has two buffers with a "ping-pong" configuration. Each buffer can store up to 960 cells. The cells are transmitted by the TDMA frame from one buffer while the ATM-AM is feeding the cells into the other buffer. Empty cells are discarded. Buffers are switched every 20 ms since the frame duration of TDMA is 20 ms. Each TDMA frame provided by the satellite link can carry up to 1104 ATM cells shared by a

number of earth stations. Each earth station has allocated time slots corresponding to allocated transmission capacity up to maximum 960 cells (equivalent to 20.352 Mbit/s).

### 3. The Satellite Link

In the demonstrator system, the EUTELSAT II satellite is used with bandwidth of 36 MHz (25 Mbit/s), transmitting at 14 GHz, receiving at 11-12 GHz, and bit error ratio of  $10^{-10}$ . The satellite propagation delay is about 250 ms. In general, the propagation delay is function of satellite orbit and earth station location.

Compared to the propagation delay, the delay within the satellite equipment is insignificant. The effects of cell loss, delay and delay variation in the equipment can be controlled to the minimum by controlling the number of applications and allocating adequate bandwidth for each application using the traffic control and resource management mechanisms.

### 4. Traffic Specifications and Applications on the Satellite Demonstrator

In the ITU-T recommendations, a guideline has been provided for classification of specific standardised services to be supported by the B-ISDN [CCIT91c].

The traffic bit rates generated by current services are in the range 64 Kbit/s to 2 Mbit/s (such as telephony, data retrieval, video telephone and video conference). Future services, such as high quality video telephony, high quality video conference and high speed data retrieval, may have much higher bit rates. Coding algorithms could be used to compress the traffic. These may reduce the amount of traffic getting into the networks, change the characteristics of the traffic, and also introduce extra delay.

Traffic parameters may be used for traffic specifications such as: peak cell rate, average cell rate, maximum burst size, mean burst duration, cell delay variation and burstiness. Some of these parameters are dependent (e.g. the burstiness with the average and peak rate).

The ATM Traffic Descriptor (TD) can be specified based on these parameters to capture the intrinsic traffic characteristics of a required connection. Traffic descriptors are part of the traffic contract and used by the Connection Admission Control (CAC) which decides if a connection can or cannot be accepted. TDs will be enforced by the usage parameter control (UPC) and network parameter control (NPC). These are often refereed as policing functions.

A number of applications have been demonstrated on the second demonstrator that include:

*Interactive image:* It is a client-server application. About 200 images are available in the server database with size range from 4 to 8 Mbits per image. The client terminals can access to these images, modified them by means of a light pen, and transfer the results back to the server database.

*Joint viewing:* A conversational type service where a white board is displayed and jointly viewed on all terminals connected to the system. Each participant can draw lines which are distinguished by different colours and the results are shown immediately on all the terminals. A picture can also be loaded to the white board and then modified.

*Multimedia communications:* The application runs on workstations equipped with video and audio devices. Three windows may be displayed on the terminals at each end of a link. For instance, one of the windows may display a video image of remote person whilst the other two display standard software applications such as word processing and drawing. Speech is also included to provide a complete videophone-like service. The inputs and modifications to text and drawing from one end-user will be simultaneously displayed to both users in the respective windows.

*Network file system (NFS):* It provides a transparent support of the existing network applications including the SUN NFS and Novel File server but with a slower response time due to the long satellite propagation delay.

## 5. Generic Traffic Control Functions

In [CCIT91c], some generic functions have been suggested as a framework for managing and controlling traffic in ATM networks. These functions can be mapped into the satellite ATM equipment. The following is a brief description of the functions:

*Network resource management (RM):* It can be used to allocate network resources in order to separate traffic flows according to service characteristics.

*Connection admission control (CAC):* It is defined as the set of actions taken by the network at the call set up phase (or during call re-negotiate phase) in order to establish whether a virtual channel or virtual path connection can or cannot be accepted.

*Usage parameter control (UPC) and network parameter control (NPC):* It is defined as the set of actions taken by the network to monitor and control traffic at the user access and the network access respectively. Their main purpose is to protect network resources from malicious as well as unintentional misbehaviour which can affect the quality of service (QoS) of other already established connections by detecting violations of negotiated parameters and taking appropriate actions.

*Priority control (PC):* The users may generate different priority traffic flows by using the cell loss priority bit. A congested network element may selectively discard cells with low priority (cell loss priority bit is set to 1) if necessary to protect as far as possible the QoS of cells with high priority (cell loss priority bit is set to 0).

*Congestion control (CC):* The set of actions taken by the network to minimise the intensity, spread and duration of congestion. These actions are triggered by congestion in one or more network elements.

Figure 4 shows the reference configuration for traffic control and resource management in the satellite ATM bridge.

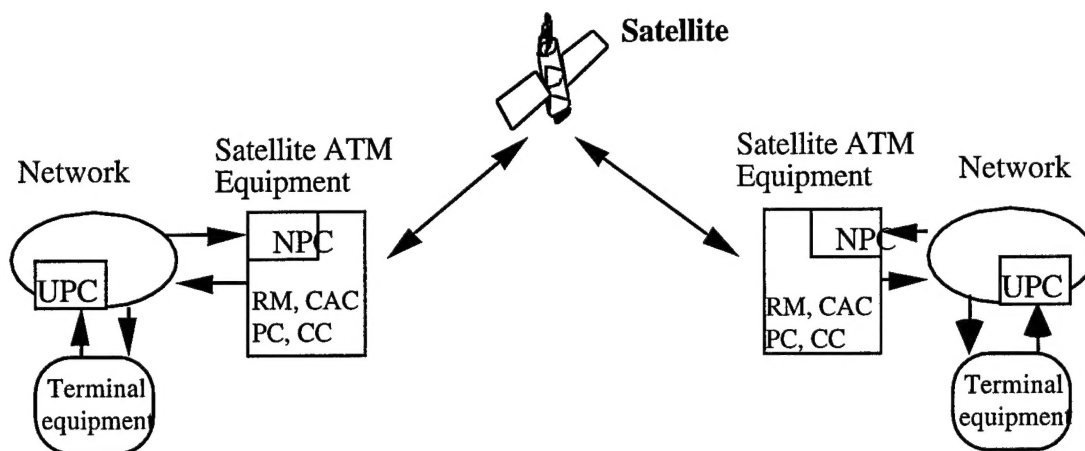


Figure 4 Traffic control and resource management in the Satellite bridge.

## 6. Satellite Resource Management

There are three levels of resource management mechanisms in the satellite bridge. The first level is controlled by the Network Control Centre (NCC) to allocate the bandwidth capacity to each earth station. The allocation is in the form of burst time plans (BTPs). Within each BTP, burst times are specified for the earth station that limit the number of cells in bursts the earth stations can transmit. The limit is that each BTP is less than or equal to 960 ATM cells and the sum of the total burst times is less than or equal to 1104 cells.

The second level is the management of the virtual paths (VPs) within each BTP. The bandwidth capacity which can be allocated to the VP is restricted by the BTP. The third level is the management of the virtual channels (VCs). It is subject to the available bandwidth resource of the VP. Figure 5 illustrates the resource management mechanisms of the bandwidth capacity. The allocation of the satellite bandwidth is done when the connections are established. Dynamic changing, allocation, sharing, or re-negotiation of the bandwidth during the connection is for further study.

To effectively implement the traffic control and resource management, the allocation of the satellite link bandwidth can be mapped into the virtual path (VP) architecture in the ATM networks and the each connection mapped into the virtual connection (VC) architecture.

The BTP can be a continuous burst or a combination of a number of sub-burst times from the TDMA frame.

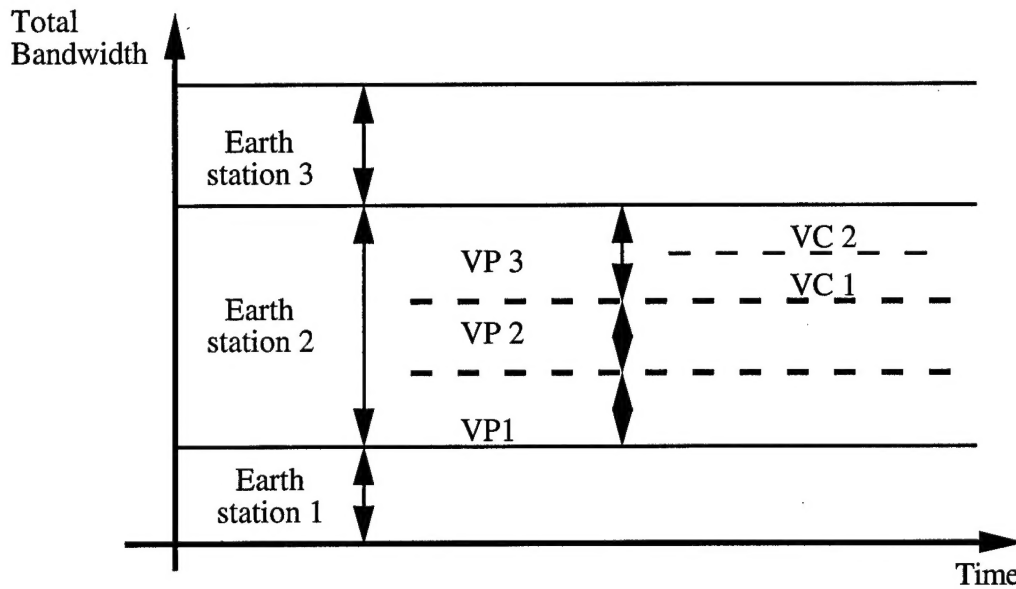


Figure 5. Satellite resource management.

## 7. Traffic and Congestion Control

### 7.1 Connection Admission Control (CAC)

The system can efficiently cope with traffic flowing from the network with bit rates up to 20.352 Mbit/s (excluding the overhead of the ATM cells) and even higher bit rates in a short burst if traffic control and resource management mechanism are used.

The CAC may accept or reject a call. It accepts the call request only when sufficient resources are available to establish the call through the whole network at its required quality of service (QoS) and maintaining the agreed QoS of existing calls. This applies as well to re-negotiation of connection parameters within a given call. In a B-ISDN environment, a call can require more than one connection for multimedia or multiparty services such as video-telephony or video-conferencing.

A connection may be required by an on-demand service, or by permanent or reserved services. The information about the traffic descriptor and required QoS is required by the CAC mechanism to determine whether the connection can be accepted or not. The CAC in the satellite has to be the integrated part of the whole network CAC mechanisms.

### 7.2 Usage Parameter Control (UPC) and Network Parameter Control (NPC)

UPC and NPC monitor and control traffic to protect the network (particularly the satellite link) and enforce the negotiated traffic contract during the call. The peak cell rate has to be controlled for all types of connections. Other traffic parameters may be subject to control such as average cell rate, burstiness and peak duration.

At cell level, cells may be allowed to pass through the connection if they comply with the negotiated traffic contract. Otherwise, the violations are recorded or counted for actions such as cell tagging or discarding. At connection level, violations may lead to the connection being released. Figure 6 illustrates the possible actions of the UPC/NPC suggested in [CCIT91d]. The Generic Cell Rate Algorithm (GCRA) is recommended as UPC/NPC in [ATMF94].

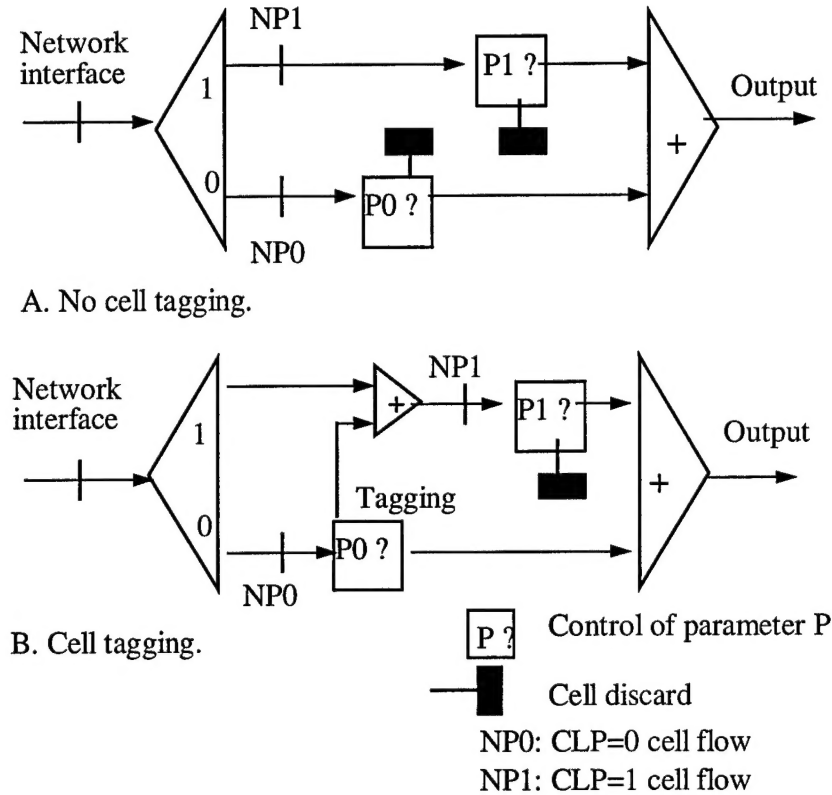


Figure 6. Possible actions of the UPC/NPC.

Traffic shaping can also be implemented in the satellite equipment to achieve a desired modification of the traffic characteristics. For example, it can be used to reduce peak cell rate, limit burst length and reduce delay variation by suitably spacing cells in time.

### 7.3 Reactive Congestion Control

Although preventive control tries to prevent congestion before it actually occurs the satellite system may experience congestion due to the earth station multiplexing buffer or switch output buffer overflow. In this case, where the network relies only on the UPC and no feedback information is exchanged between the network and the source, no action can be taken once congestion has occurred.

Many applications, mainly handling data transfer, have the ability to reduce their sending rate if the network requires them to do so. Likewise, they may wish to increase their sending rate if there is extra bandwidth available within the network. This kind of applications are supported by the ABR service class. The bandwidth allocated for such applications is dependent on the congestion state of the

network. Rate-based control was recommended for ABR services, where information about the state of the network is conveyed to the source through special control cells called Resource Management (RM) cells [ATMF94]. Rate information can be conveyed back to the source in two forms:

- i) Binary Congestion Notification (BCN) using a single bit for marking the congested and not congested states.
- ii) Explicit Rate (ER) indication, with which the network notifies the source of the exact bandwidth share it should be using in order to avoid congestion.

The earth stations can determine congestion either by measuring the traffic arrival rate or by monitoring the buffer status.

### 8. Measured Performance and Impact on the Applications

The first CATALYST demonstration took place in December 1992 and involved the first transmission of ATM cells via satellite in Europe. In March 1994, the second demonstration was carried out. The aim of the second demonstrator was to demonstrate the capacity of the satellite ATM equipment supporting different applications. In the meantime, some efforts were made to take some performance measurements. The measurements were mainly on the Round Trip Time (RTT) delay for different data size on the demonstrator. Figure 7 illustrated the measured performance taken from the second demonstrator.

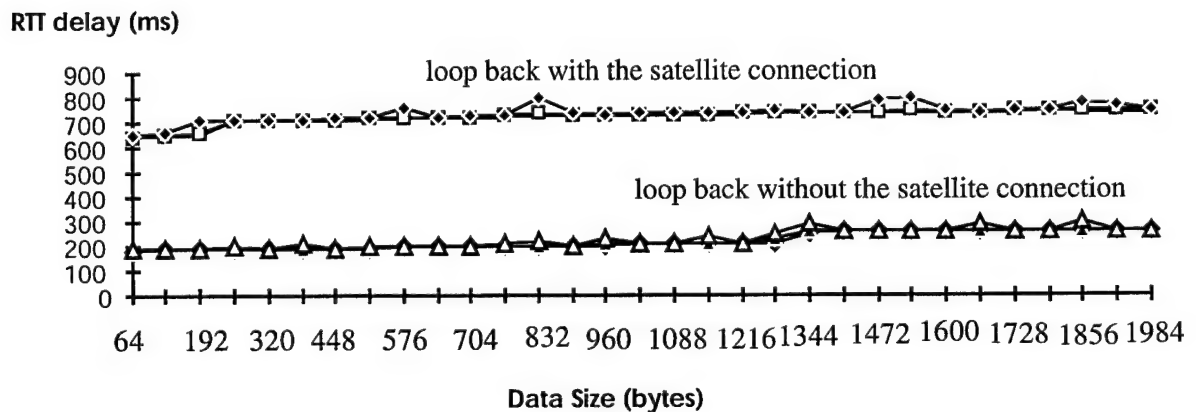


Figure 7. The measured performance on the second demonstrator.

The measurements were taken based on the end-to-end configuration. Two Ethernet local area networks (LANs) were interconnected through the CATALYST ATM satellite Equipment. There were two groups of measurements: (a) the equipment loop back without the satellite connection; and (b) the equipment loop back with the satellite connections. For each of the groups, different data sizes were

transmitted. 20 data packets were transmitted for each data size. The round trip time (RTT) delays were recorded, and the maximum, minimum and average RTT delay calculated.

The measured results showed that RTT delay without the satellite connection was about 188-269 ms and the RTT delay with the satellite connection was about 649-780 ms where the satellite two-way propagation delay is about 500 ms (the end-to-end one way propagation delay was about 250 ms). There were also some delay variations due to re-transmission in the Ethernet LAN and scheduling the transmission of the 20 ms TDMA frame. Such variations were very small for small data size.

The long delay due to the nature of satellite link has a significant impact on the applications that include:

*Throughput:* Applications using connection oriented transport level protocols (such as the TCP/IP) needed to wait for the acknowledgements of packet arrival to support the flow control mechanism and to provide a reliable transport layer service. If a packet got lost, the protocol would re-transmit the packet. The throughput was restricted by the waiting for acknowledgement. The window size of the protocol can be used to adjust the amount of data to be sent before waiting for the acknowledgement. If connectionless protocols such as the UDP/IP were used, there was no re-transmission and no guarantee that the packet will arrive at its destination. On the basis of the measurement and some simulation results, the following empirical formula was produced to estimate the throughput of burst traffic based on connection oriented protocols with acknowledgement:

$$\text{Throughput} = \text{WindowSize} / (\text{TransmissionTime} + \text{RTT}).$$

*Request and response services:* the long delay affects the throughput of the request and response type services (for example, the interactive service of login to a remote system). Users experience slow response time and slow information retrieval. The time can be estimated as:

$$\text{RequestResponseTime} = \text{GenerateRequest} + \text{ProcessRequest} + \text{RTT}.$$

*Video and voice services:* real time services are more sensitive to the delay and waiting time for acknowledgement. As long as the delay variation is restricted to a very small value or the signal timing can be recovered at the destination, the satellite can still provide the connection at high quality. The mean delay variation is estimated as:

$$\text{MeanDelayVariation} = \text{TDMAFrameTime} / 2.$$

*Text or data services:* These are not sensitive to the delay and often require a reliable transport level protocol. The throughput is restricted and parameters of the protocols need to be adjusted or new protocol designed to suit the feature of satellite communications.

*Buffer Requirement:* Since the satellite ATM equipment interfaces to the high speed networks, it is important to allow these networks to transmit burst traffic at a high speed to take the advantages of

ATM technology. Buffers are required to absorb the traffic fluctuations. The following is an estimation of the buffer requirement (in number of ATM cells):

$$\text{BufferReq} = (\text{TransSpeed} - \text{LinkSpeed}) * \text{BurstSize} / (53 * \text{TransSpeed}).$$

Quality of transfer parameters (Cell Error Ratio, Cell Loss Ratio) were measured during the 5th demonstrator in November 1994. The measurements of the quality of transfer parameters were made against varying link quality level. These measurements did not require a satellite connection because the gaussian error distribution of the satellite path can be reproduced with a noise source at I.F. Furthermore, the measurements performed using a noise generator to fix the link BER are more accurate because the conditions are stable during the measurement duration.

The measurement configuration is shown in Figure 8. The ATM traffic was generated and analysed with a Tekelec TE-875 test tool connected to the CATALYST subnetwork through the ATM-AM 155Mbps optical interface module designated the Line Termination (LT). The traffic terminal is connected at I.F. to a noise generator (HP3708A) used to emulate the satellite link. The Eb/No ratio is set in order to fix the link BER which is measured with a G.703 traffic generator (TE820) connected to a TIM called MIA2G.

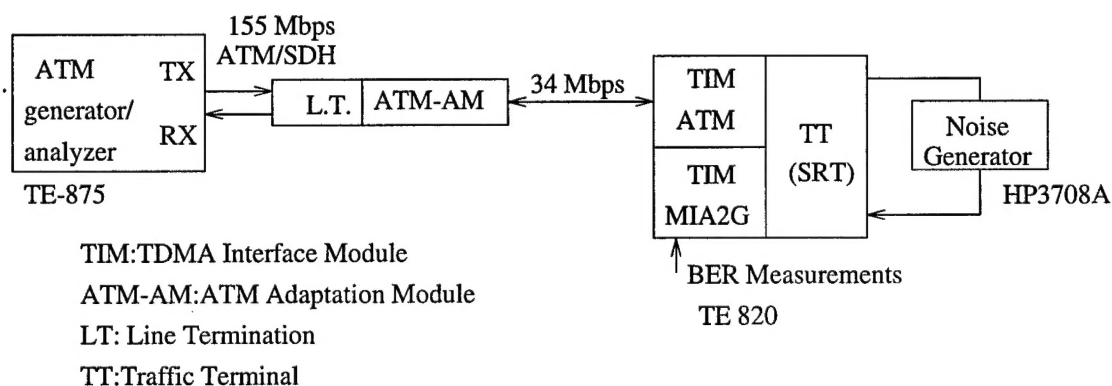


Figure 8. Measurement configuration through a single CATALYST chain

Different measurements were performed changing the transmission channel quality (Eb/No ratio) and the data rate (from 2Mbps to 18Mbps). Simultaneously with a test running on the TE-875, the link BER was measured with the TE-820. Figure-9 shows some of the measured CLR and CER for different Eb/No on the same graph.

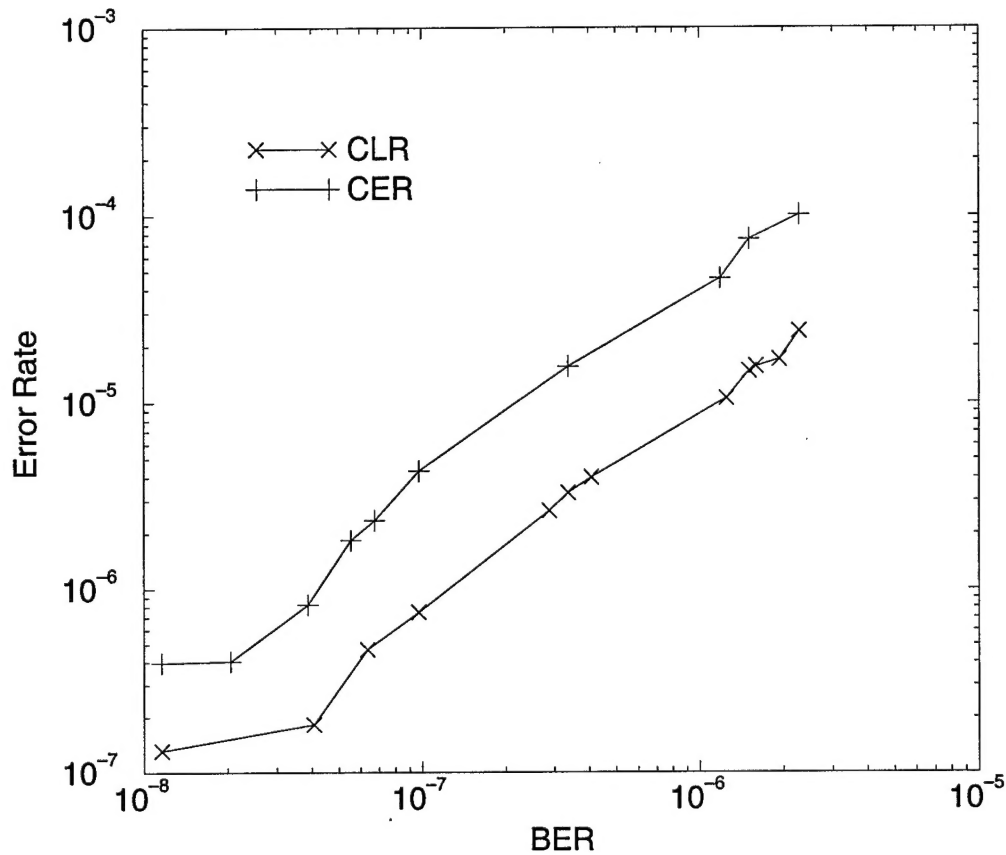


Figure 9. CLR and CER Measurements

The ATM performance parameters are related to the link bit error rate and are also dependent on the bit error distribution. In the case of random distribution of errors as in optical fibre links, the ATM header error correction (HEC) mechanism which is capable of correcting single-bit errors corrects most errors encountered. However in satellite links, the link coding mechanism used produces burst of errors. More than one error in the header can not be corrected by the ATM HEC.

The CLR is proportional to the BER and is higher than for links with random error distribution. The link coding is however necessary to reduce the error rate of payload data. To avoid the effect of burst error in the ATM QoS, improved coding techniques (such as Reed-Solomon code and interleaving) could be used to spread bit errors over the ATM cell headers.

## 9. Evolution

Whilst fibre optics is rapidly becoming the preferred carrier for high bandwidth communication services, satellite systems can play an important role in the B-ISDN. The satellite network configuration and capacity can be increased gradually to match the B-ISDN traffic evolution at each time.

The role of satellites in high-speed networking will evolve according to the evolution of the terrestrial ATM based B-ISDN. However two main roles can be identified:

- i) The introduction phase when satellites will compensate the lack of sufficient terrestrial high bit rate links mainly by interconnecting a few regional or national distributed broadband networks, usually called 'Broadband Islands'.
- ii) The maturation phase when the terrestrial broadband infrastructure will have reached some degree of maturity. In this phase, satellites are expected to provide broadcast service and also cost effective links to rural areas complementing the terrestrial network. Satellite networks will provide broadband links for a large number of end users through a User Network Interface (UNI) to access the ATM B-ISDN. They are also ideal for interconnecting mobile sites. Furthermore they provide a back-up solution in case of failure of the terrestrial systems.

In the first scenario, satellite links provide high bit rate links between broadband nodes or broadband islands. The RACE CATALYST project was a demonstrator for this scenario and showed the compability of satellite technology with ATM and the terrestrial B-ISDN. The interfaces with satellite links in this mode are of the NNI type. This scenario is characterized by a relatively small number of large earth stations which have a relatively large average bit rate. The cost and the size of the earth station has a small impact on the suitability of the satellite solution.

In the second scenario the satellite system is located at the border of the B-ISDN and provides access links to a large number of users. This scenario is characterized by a large number of earth stations whose average and peak bit rates are limited. The traffic at the earth station is expected to show large fluctuations. Therefore the multiple access scheme will considerably effect the performance of the system. Furthermore the cost and size of the earth station have a large impact on the suitability of the satellite solution.

Very Small Aperture Terminal (VSAT) satellite systems could be used for the second scenario. On-board processing (OBP) satellites with cell switching capabilities and spot beams would make B-ISDN access affordable for a large number of users by lowering earth-station cost and providing bandwidth on demand [ORS96]. The ACTS VANTAGE project is investigating this scenario by field trials.

## 10. Conclusion

This paper presented the experiments and architecture of ATM via satellite based on the demonstrators developed by the CATALYST project. The architecture and modelling of the satellite ATM system were developed based on implemented equipment. The paper discussed relevant issues based on the demonstrators, including traffic specifications, traffic and congestion control and resource management.

The second and fifth demonstrator had successfully demonstrated the capability of ATM via satellite, to support the applications including data, voice, video and multimedia communications. Although only limited measurements were taken from the demonstrators, these results were still be useful to explain the behaviour of the applications on the demonstrator. The measurements provided some reference values for the system performance. These values will be useful for selection and trade-off between different protocols and parameters and the design of new protocols to suit the nature of satellite communications.

### Acknowledgements

The authors gratefully acknowledge the support from the Engineering and physical Science Research Council (EPSRC) and the European RACE programme, the RACE II CATALYST project (R2074)

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